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(54) **MEMS SEE-SAW ARRAY FOR DYNAMIC GAIN EQUALIZATION OF DWDM SYSTEMS**

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(52) **U.S. Cl.** **385/140**; 385/31; 385/18; 385/37

(58) **Field of Search** 385/140, 16, 17, 385/18, 31

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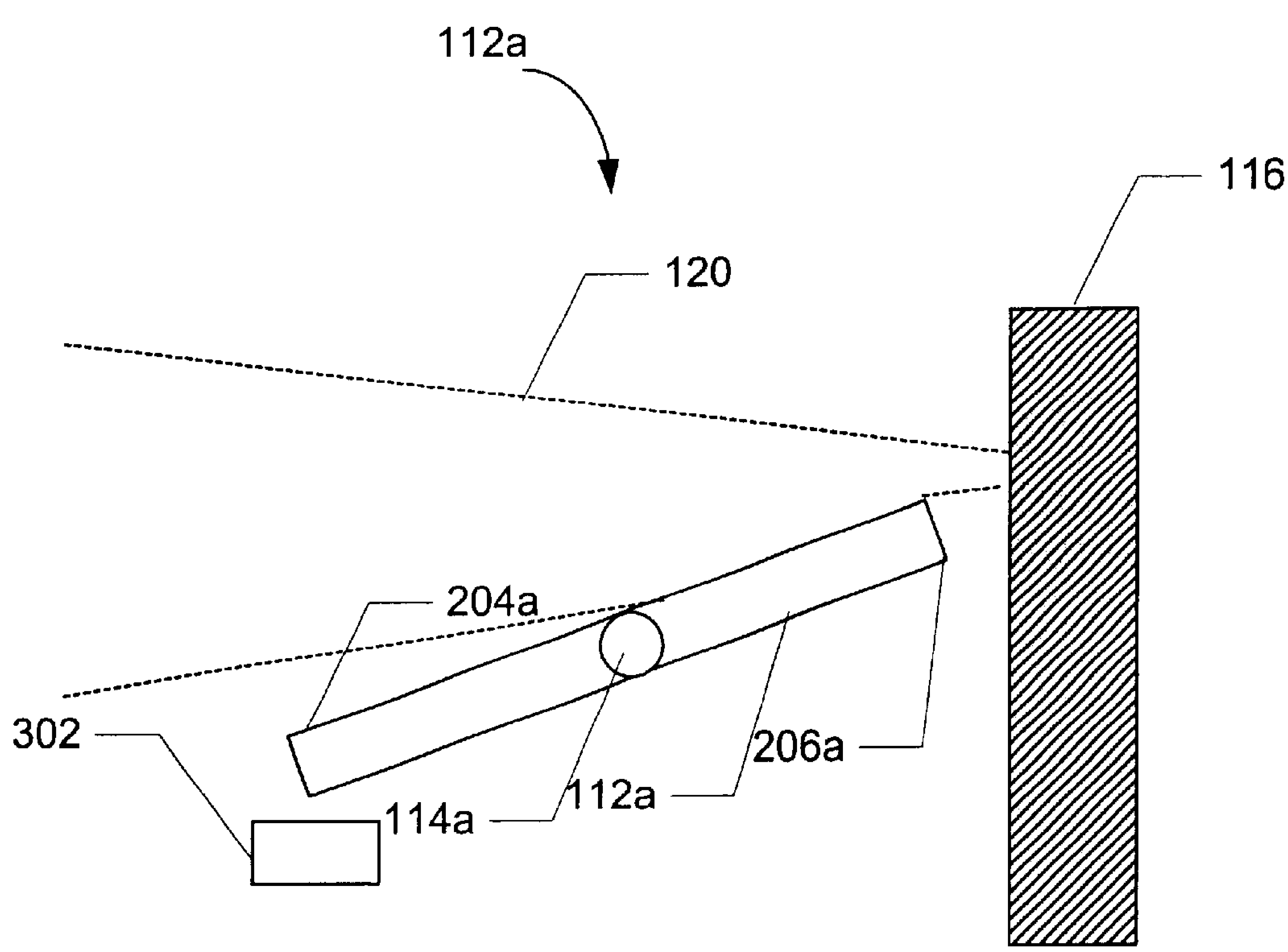
(57) **ABSTRACT**

A dynamic gain equalizer (DGE) includes: a mirror; an electrode; and a lever with a first end and a second end opposite to the first end, where the lever is capable of rotating about a fulcrum, where the lever rotates the first end toward the electrode when the electrode is charged such that the second end blocks a portion of a channel from reaching the mirror, where an unblocked portion of the channel is reflected by the mirror. By manipulating the charge on the electrode, the rotation of the lever is controlled, determining how much of the light is blocked by the lever. Each lever in an array can attenuate a channel or a group of channels of a composite optical signal by a different amount. The DGE provides a significant range of blockage and can be closely spaced. It provides ease in integrating channel monitoring into the DGE.

15 Claims, 5 Drawing Sheets



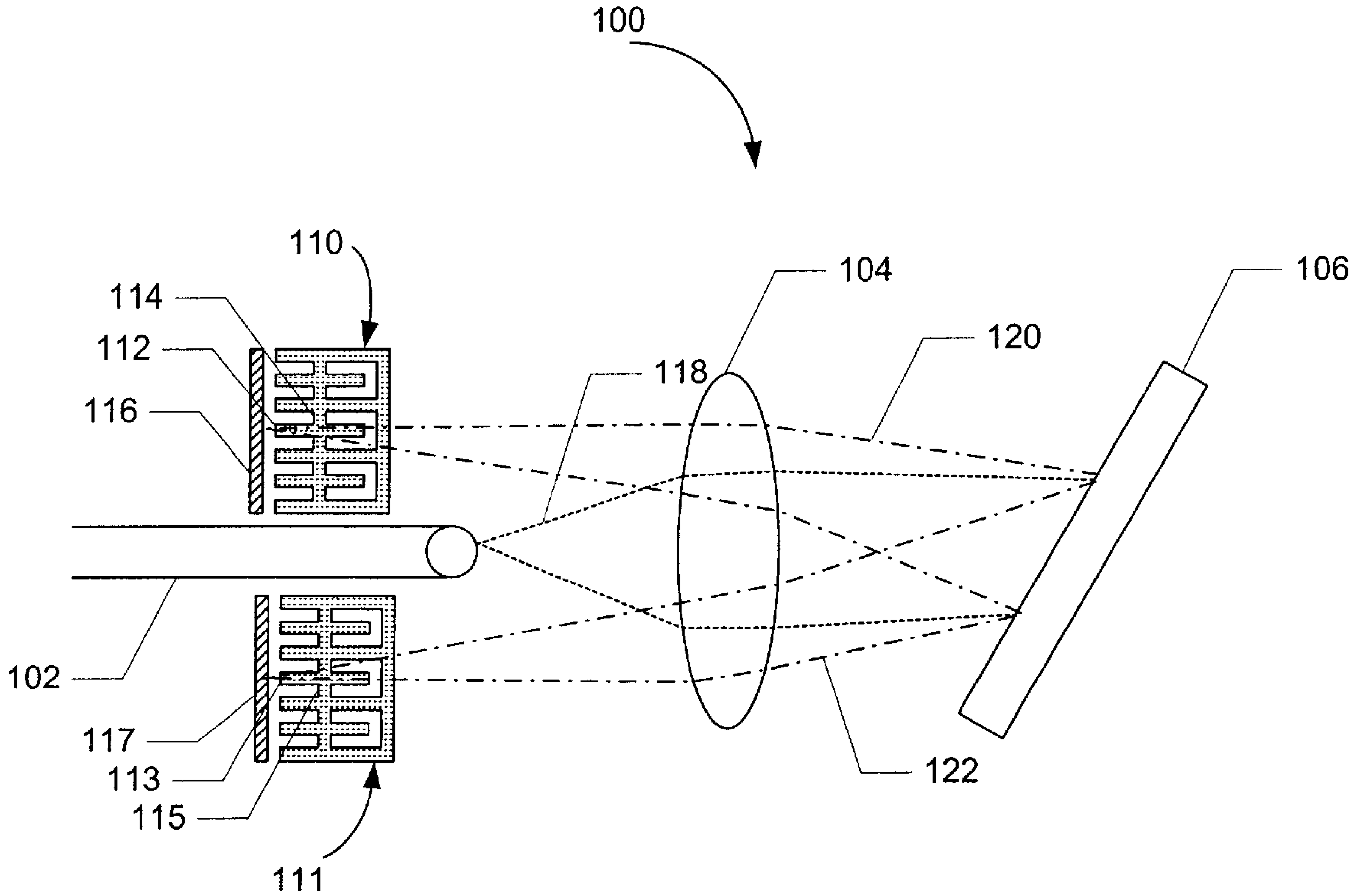
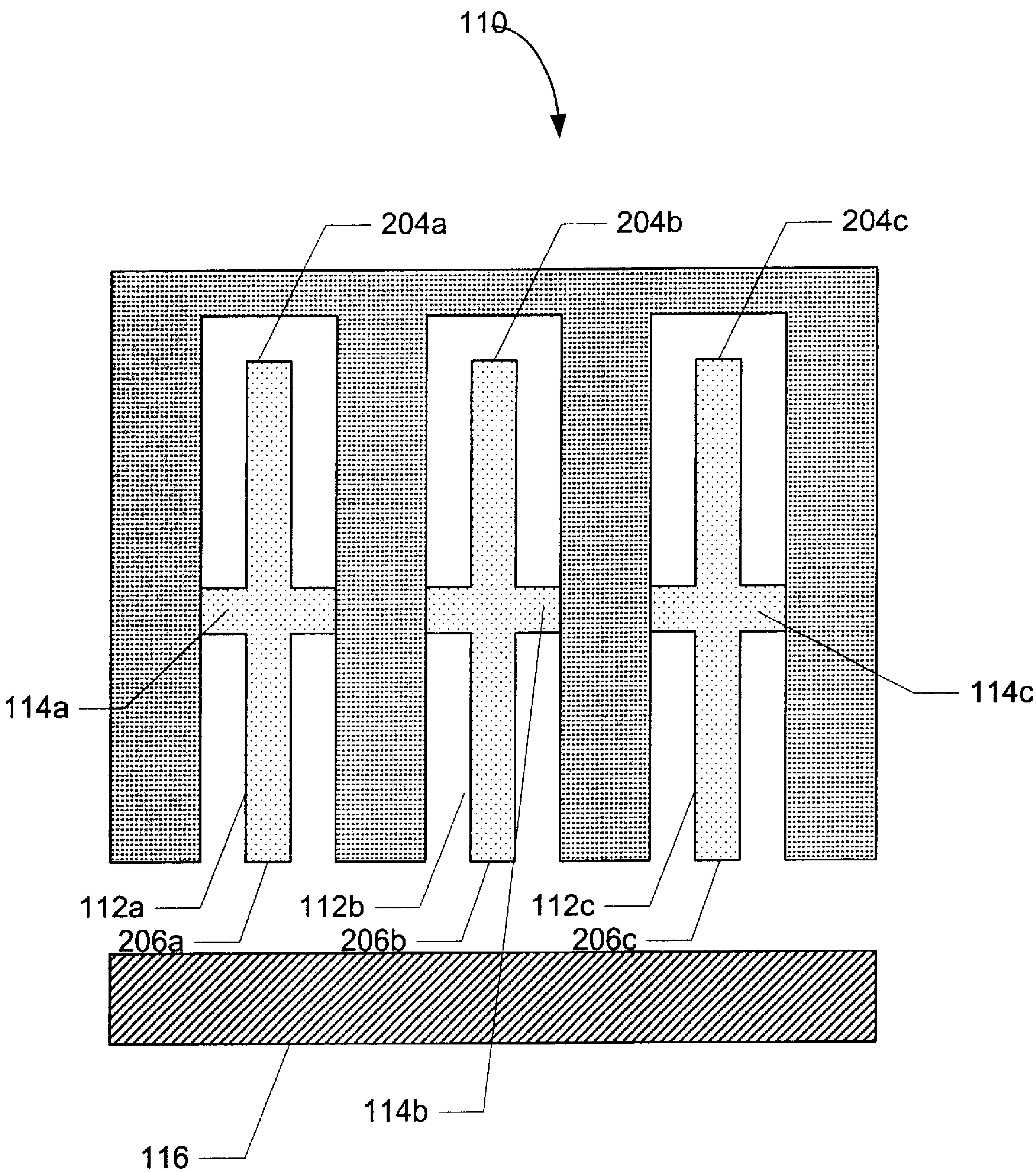


FIG. 1


110
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204c
114a
114c
112a
112b
112c
206a
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114b
116

FIG. 2

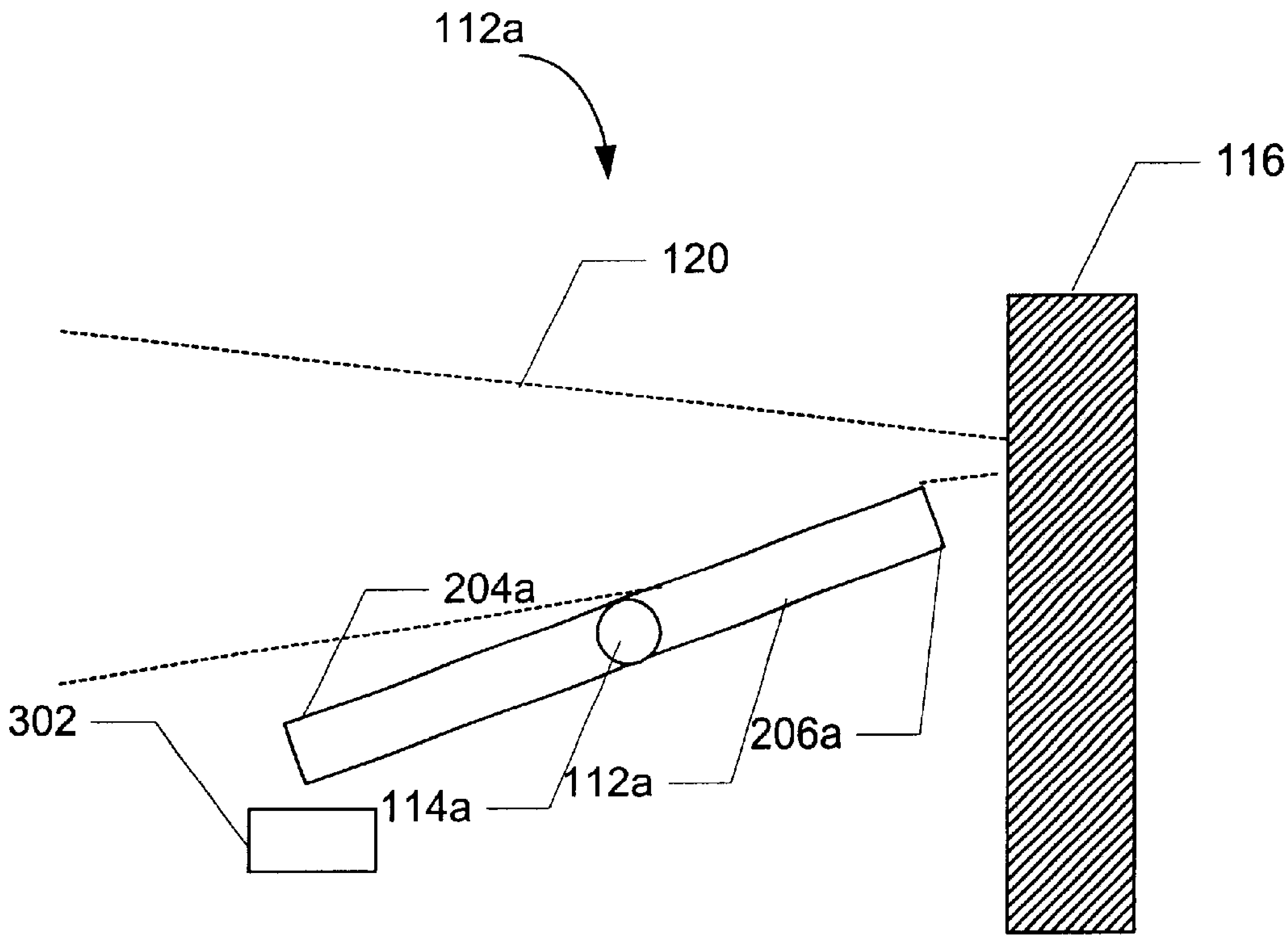

FIG. 3

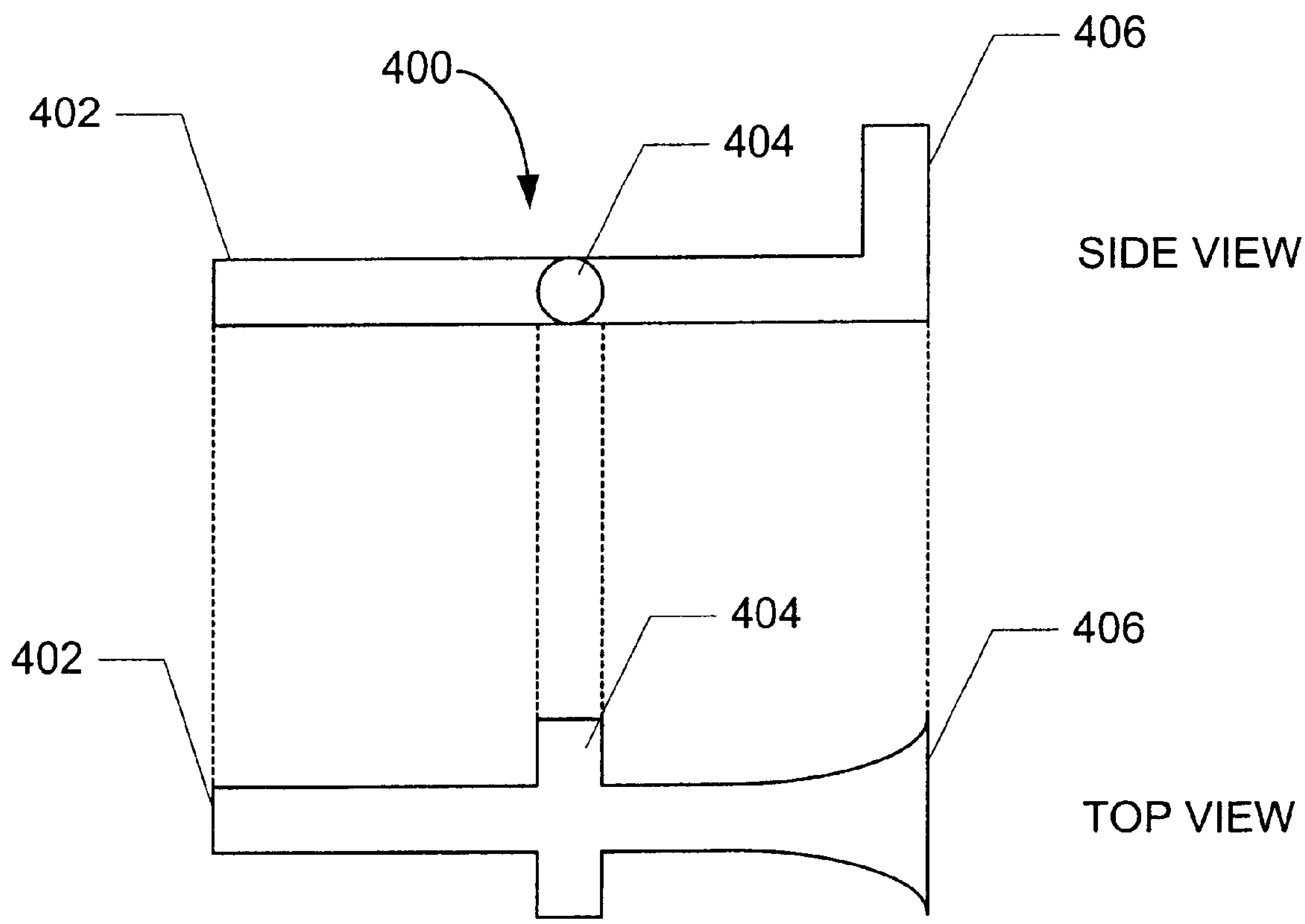

FIG. 4

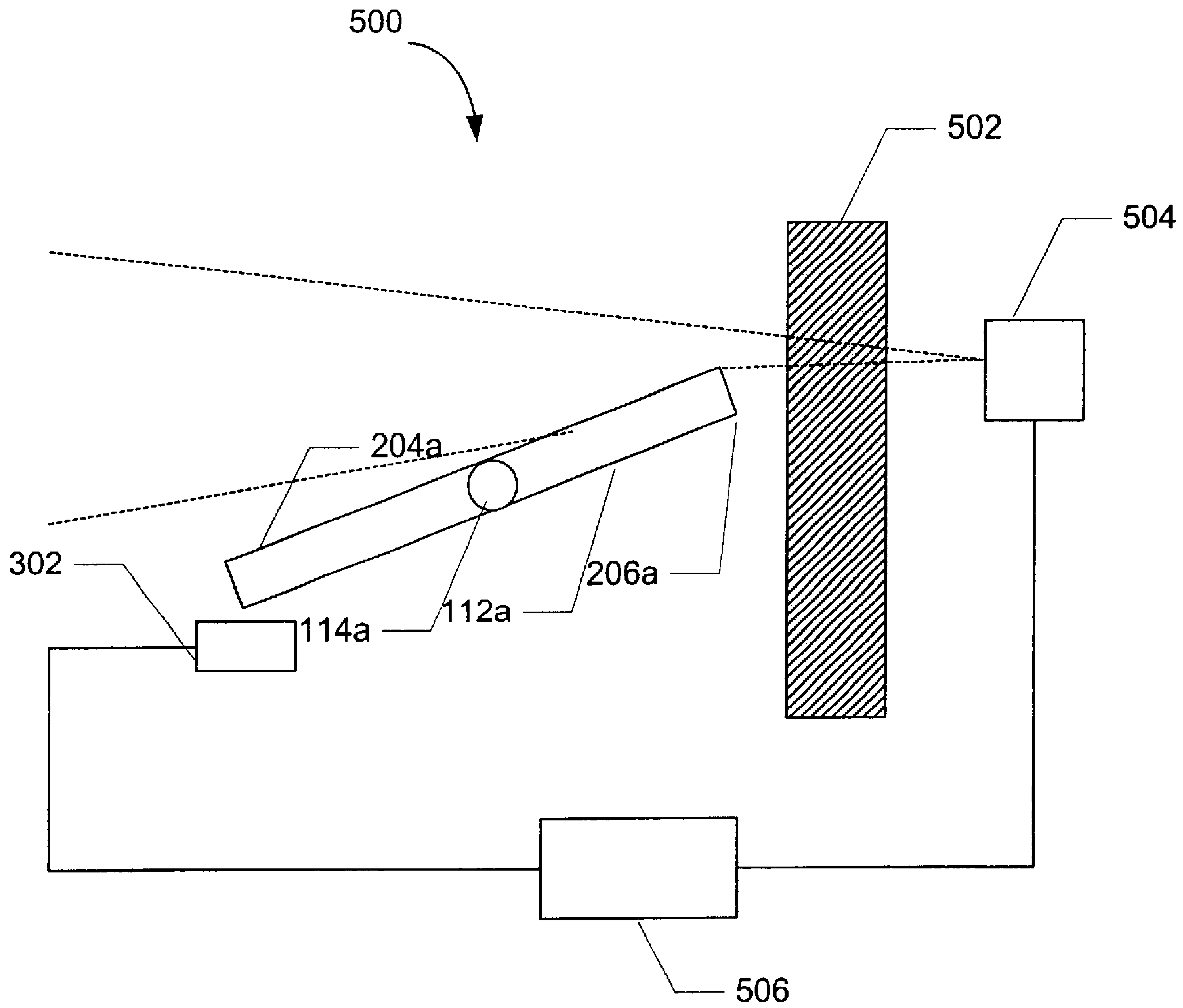

FIG. 5

MEMS SEE-SAW ARRAY FOR DYNAMIC GAIN EQUALIZATION OF DWDM SYSTEMS

FIELD OF THE INVENTION

The present invention relates to dense wavelength division multiplexed systems, and more particularly to gain equalization in dense wavelength division multiplexed systems.

BACKGROUND OF THE INVENTION

Fiber optic networks are becoming increasingly popular for data transmission due to their high speed, high capacity capabilities. In conventional wavelength division multiplexed (WDM) fiber optic networks, signals travel along optical fibers toward a destination node. Occasionally, the signals must be amplified by an optical amplifier, such as an Erbium Doped Fiber Amplifier (EDFA), due to attenuation of the signal strength.

The power level of digital or analog data transmissions over any given segment of the WDM network will generally vary over time. With increasing network complexity, rapid or short-term power fluctuations in signal levels are becoming of increasing concern. Such fluctuations may be caused by fluctuations in the number of data channels carried by the network and variability of the routing of the various signal channels prior to their arrival at that segment. Furthermore, both the total gain and the average gain per channel provided by an optical amplifier may depend upon the number of channels carried by the network at the point of the amplifier. This latter quantity can vary virtually instantaneously in the network depending upon network traffic conditions and routing configurations. For the above reasons, the total power level can fluctuate rapidly within a segment of a complex WDM network.

Accordingly, there is a need for a method and system for dynamic gain attenuation. The present invention addresses such a need.

SUMMARY OF THE INVENTION

A dynamic gain equalizer (DGE) includes: a mirror; an electrode; and a lever with a first end and a second end opposite to the first end, where the lever is capable of rotating about a fulcrum, where the lever rotates the first end toward the electrode when the electrode is charged such that the second end blocks a portion of a channel from reaching the mirror, where an unblocked portion of the channel is reflected by the mirror. By manipulating the charge on the electrode, the rotation of the lever is controlled, determining how much of the light is blocked by the lever. Each lever in an array can attenuate a channel or a group of channels of a composite optical signal by a different amount. The DGE provides a significant range of blockage and can be closely spaced. It provides ease in integrating channel monitoring into the DGE.

BRIEF DESCRIPTION OF THE FIGURES

FIG. **1** illustrates a preferred embodiment of a dynamic gain equalizer in accordance with the present invention.

FIG. **2** illustrates, in more detail, a top view of a MEMS see-saw array utilized in the dynamic gain equalizer in accordance with the present invention.

FIG. **3** illustrates, in more detail, a side view of a lever of the preferred embodiment of the MEMS see-saw array utilized in the dynamic gain equalizer in accordance with the present invention.

FIG. **4** illustrates an alternative shape for the lever in the MEMS see-saw array utilized in the dynamic gain equalizer in accordance with the present invention.

FIG. **5** illustrates a preferred embodiment of a side view of a lever of the dynamic gain equalizer with channel monitoring in accordance with the present invention.

DETAILED DESCRIPTION

The present invention provides a method and system for dynamic gain attenuation. The following description is presented to enable one of ordinary skill in the art to make and use the invention and is provided in the context of a patent application and its requirements. Various modifications to the preferred embodiment will be readily apparent to those skilled in the art and the generic principles herein may be applied to other embodiments. Thus, the present invention is not intended to be limited to the embodiment shown but is to be accorded the widest scope consistent with the principles and features described herein.

The method and system in accordance with the present invention provides a dynamic gain equalizer (DGE) which comprises a micro-electromechanical system (MEMS) see-saw array. The array comprises a mirror and at least one lever which is capable of rotating about a fulcrum. At a first end of the lever is an electrode which, when charged, causes the lever to rotate such that the first end moves toward the electrode. When the electrode is charged, the second end of the lever, opposite to the first end, blocks a portion of a light from reaching the mirror. The unblocked part of the light is reflected from the mirror. By manipulating the amount of charge on the electrode, the amount of rotation of the lever is controlled. The amount of rotation of the lever determines how much of the light is blocked by the lever. The more light the lever blocks, the more of the light is attenuated. Each lever can attenuate a channel or a group of channels of a composite optical signal by a different amount, thus providing dynamic gain attenuation.

To more particularly describe the features of the present invention, please refer to FIGS. **1** through **5** in conjunction with the discussion below.

FIG. **1** illustrates a preferred embodiment of a dynamic gain equalizer in accordance with the present invention. The DGE **100** comprises a fiber **102** which functions both as an input and an output fiber. Separate fibers for signal input and output may be used instead. The DGE **100** also comprises a lens **104** optically coupled to the fiber **102**, a diffraction grating **106** optically coupled to the lens **104** at a side opposite to the fiber **102**, and at least one MEMS see-saw array **110–111** optically coupled to the lens **104** at a side opposite to the diffraction grating **106**. Each array **110, 111** comprises at least one lever **112, 113** which is able to rotate about a fulcrum **114, 115**. Each array **110–111** also comprises a mirror **116, 117**.

A composite optical signal **118** comprising a plurality of channels enters the DGE **100** via the fiber **102**. The signal **118** is collimated by the lens **104** onto the diffraction grating **106**. The diffraction grating **106** reflects each wavelength of the signal **118** by a different amount, as is well known in the art. For example, channels **120** and **122** are reflected back toward the lens **104**. The lens **104** focuses these channels **120, 122** onto the MEMS see-saw arrays **110** and **111**, respectively. The arrays **110, 111** are placed such that its levers **112, 113** is able to block a portion of the channels **120, 122** from reaching the mirror **116, 117**, respectively. To block, these levers **112, 113** are rotated about their fulcra **114, 115** in varying amounts, depending upon the amount of attenuation required by each channel. The attenuated channels **120**, **122** are then reflected from the mirrors **116**, **117** to the lens **104**. The lens **104** focuses them onto the diffraction grating **106**. The diffraction grating **106** recombines the attenuated channels **120**, **122** back into a composite optical signal **118**. This signal **118** is reflected through the lens **104** to the fiber **102**.

FIG. **2** illustrates, in more detail, a top view of a MEMS see-saw array utilized in the dynamic gain equalizer in accordance with the present invention. The array **110** resides in a substrate **202**. Using semiconductor fabrication techniques, the substrate **202** is etched such that at least one lever **112***a*, **112***b*, **112***c* is formed. Each of the levers **112***a*, **112***b*, **112***c* is capable of rotating about a fulcrum **114***a*, **114***b*, **114***c*. Each lever **112***a*, **112***b*, **112***c* has a first end **204***a*, **204***b*, **204***c* and a second end **206***a*, **206***b*, **206***c*. Electrodes (not shown) underneath the levers **112***a*, **112***b*, **112***c* may be charged such that the first ends **204***a*, **204***b*, **204***c* of the levers **112***a*, **112***b*, **112***c* are rotated toward the electrodes about their fulcra **114***a*, **114***b*, **114***c*. Each lever **112***a*, **112***b*, **112***c* may be caused to rotate in different amounts. When rotated, each lever **112***a*, **112***b*, **112***c* blocks a portion of a channel from reaching the mirror **116**, attenuating the gain of that channel.

FIG. **3** illustrates, in more detail, a side view of a lever of the preferred embodiment of the MEMS see-saw array utilized in the dynamic gain equalizer in accordance with the present invention. The lever **112***a* is capable of rotating about its fulcrum **114***a*. At the first end **204***a* of the lever **112***a* is an electrode **302** which, when charged, causes the lever **112***a* to rotate such that the first end **204***a* moves toward the electrode **302**. When the electrode **302** is not charged or is of a low charge, the lever **112***a* does not interfere with the channel **120**. All of the channel **120** reaches the mirror **116** and is reflected. In this instance, the gain of the channel **120** is not attenuated. When the electrode **302** is charged, the second end **206***a* of the lever **112***a*, opposite to the first end **204***a*, blocks a portion of the channel **120** from reaching the mirror **116**. The unblocked portion of the channel **120** is reflected from the mirror **116**. By manipulating the amount of charge on the electrode **302**, the amount of rotation of the lever **112***a* is controlled. The amount of rotation of the lever **112***a* determines how much of the channel **120** is blocked by the first end **204***a* of the lever **112***a*. The more of the channel **120** the lever **112***a* blocks, the more the gain of the channel **120** is attenuated.

The portion of the lever **112***a* between the fulcrum **114***a* and the second end **206***a* may be longer than the portion between the fulcrum **114***a* and the first end **204***a*. A greater amount of movement of the second end **206***a* results from each movement of the first end **204***a*, providing a greater range of blockage.

FIG. **4** illustrates an alternative shape for the lever in the MEMS see-saw array utilized in the dynamic gain equalizer in accordance with the present invention. The lever **400** has a first end **402** which is broader than the second end **406**. Thus, when the electrode (not shown) is charged, the first end **402** of the lever **400** rotates about its fulcrum **404** toward the electrode, moving the second end **406** into the path of a light. Because the second end **406** is broader, it allows the first end **402** to be smaller than the first end **204***a* of the lever **112***a* (FIG. **3**). With a smaller first end **402**, its electrode (not shown) can also be smaller. This allows a plurality of the levers **400** to be more closely spaced in an array without electrical coupling. With the levers more closely spaced, the array can attenuate more closely spaced channels or has wider passband.

An additional advantage of the DGE **100** in accordance with the present invention is the ease of integrating channel monitoring into the device. FIG. **5** illustrates a preferred embodiment of a side view of a lever of the dynamic gain equalizer with channel monitoring in accordance with the present invention. In addition to the components illustrated in FIG. **3**, the DGE **500** has a mirror **502** which allows some of the light to leak through, a photodetector **504** at the other side of the mirror **502** from the lever **112***a*, and a controller **506** coupled to the photodetector **504** and the electrode **302**. The photodetector **504** captures the light leakage through the mirror **502**. This light leakage is then analyzed by the controller **506**. The controller **506** uses this analysis to manipulate the charge on the electrode **302** to rotate the lever **112***a* so that a desired attenuation of a channel is obtained. In this manner, the attenuation of the channel is monitored.

A method and system for dynamic gain attenuation has been disclosed. The dynamic gain equalizer (DGE) in accordance with the present invention comprises a micro-electromechanical system (MEMS) see-saw array. The array comprises a mirror and at least one lever which is capable of rotating about a fulcrum. At a first end of the lever is an electrode which, when charged, causes the lever to rotate such that the first end moves toward the electrode. When the electrode is charged, the second end of the lever, opposite to the first end, blocks a portion of a light from reaching the mirror. The unblocked portion of the light is reflected from the mirror. By manipulating the amount of charge on the electrode, the amount of rotation of the lever is controlled. The amount of rotation of the lever determines how much of the light is blocked by the lever. The more light the lever blocks, the more the gain of the light is attenuated. Each lever can attenuate a channel of a composite optical signal by a different amount, thus providing dynamic gain attenuation. The levers in the DGE can provide a significant range of blockage and can be closely spaced. It also provides ease in integrating channel monitoring into the DGE.

Although the present invention has been described in accordance with the embodiments shown, one of ordinary skill in the art will readily recognize that there could be variations to the embodiments and those variations would be within the spirit and scope of the present invention. Accordingly, many modifications may be made by one of ordinary skill in the art without departing from the spirit and scope of the appended claims.

What is claimed is:

1. A micro-electromechanical system (MEMS), comprising:

a mirror;

an electrode; and

a lever with a first end and a second end opposite to the first end, wherein the lever is capable of rotating about a fulcrum, wherein the lever rotates the first end toward the electrode when the electrode is charged such that the second end blocks a portion of a channel from reaching the mirror, wherein an unblocked portion of the channel is reflected by the mirror.

2. The MEMS of claim **1**, wherein a portion of the lever between the fulcrum and the second end is longer than a portion of the lever between the fulcrum and the first end.

3. The MEMS of claim **1**, wherein the second end of the lever is broader than the first end of the lever.

4. The MEMS of claim **1**, further comprising:

a photodetector optically coupled to the mirror at a side opposite to the lever; and

a controller coupled to the photodetector and the electrode.

5. A MEMS see-saw array, comprising:

a mirror;

a plurality of electrodes; and

a plurality of levers, each lever corresponding to one of the plurality of electrodes, wherein each lever comprising a first end and a second end opposite to the first end, wherein each lever is capable of rotating about a fulcrum, wherein each lever rotates the first end toward its corresponding electrode when the corresponding electrode is charged such that the second end blocks a portion of a channel from reaching the mirror, wherein an unblocked portion of the channel is reflected by the mirror.

6. The array of claim **5**, wherein a portion of the lever between the fulcrum and the second end is longer than a portion of the lever between the fulcrum and the first end.

7. The array of claim **5**, wherein the second end of the lever is broader than the first end of the lever.

8. The array of claim **5**, further comprising:

a plurality of photodetectors optically coupled to the mirror at a side opposite to the plurality of levers; and

a plurality of controllers coupled to the plurality of photodetectors and the plurality of electrodes.

9. A dynamic gain equalizer (DGE), comprising:

a fiber;

a lens optically coupled to the fiber;

a diffraction grating optically coupled to the lens at a side opposite to the fiber; and

at least one MEMS see-saw array optically coupled to the lens at a side opposite to the diffraction grating, comprising:

a mirror,

an electrode, and

a lever with a first end and a second end opposite to the first end, wherein the lever is capable of rotating about a fulcrum, wherein the lever rotates the first end toward the electrode when the electrode is charged such that the second end blocks a portion of a channel from reaching the mirror, wherein an unblocked portion of the channel is reflected by the mirror.

10. The DGE of claim **9**, wherein a portion of the lever between the fulcrum and the second end is longer than a portion of the lever between the fulcrum and the first end.

11. The DGE of claim **9**, wherein the second end of the lever is broader than the first end of the lever.

12. The DGE of claim **9**, wherein the at least one MEMS see-saw array further comprises:

a photodetector optically coupled to the mirror at a side opposite to the lever; and

a controller coupled to the photodetector and the electrode.

13. A method for dynamic gain equalization, comprising the steps of:

(a) providing a composite optical signal, the composite optical signal comprising a plurality of channels;

(b) demultiplexing the composite optical signal into the plurality of channels;

(c) directing each of the plurality of channels toward a mirror;

(d) blocking a portion of the plurality of channels from reaching the mirror by a lever having a first end and a second end opposite to the first end, wherein the lever is capable of rotating about a fulcrum, wherein the lever rotates the first end toward an electrode when the electrode is charged such that the second end blocks the portion.

14. The method of claim **13**, further comprising:

(e) reflecting an unblocked portion of the plurality of channels from the mirror; and

(f) multiplexing the reflected unblocked portion of the plurality of channels.

15. The method of claim **13**, further comprising:

(e) detecting a light leakage through the mirror;

(f) analyzing the light leakage; and

(g) controlling a charge to the electrode based on the analyzing step (f).

* * * * *